Manure management and nutrient loss under winter conditions: A literature review

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ABSTRACT: Excessive losses of nitrogen (N) and phosphorus (P) from agricultural fields have detrimental impacts on environmental quality. Nutrient management guidelines, such as the P index, are designed to minimize the risk of nutrient loss with minimal disruption to the whole farm operation. Restricting winter spreading of manure, which is common to most management guidelines developed for cold climates, is a contentious issue in the northern-tier states of the United States and almost all provinces of Canada. Producers have strong opinions with regard to the merits of winter spreading and arguments against the alternative practice of manure storage. The purpose of this paper is to review the results of scientific studies relevant to the issue of winter spreading of manure, and identify needs for additional research in this area. Collectively, these studies illustrate the complexity of N and P dynamics in response to a wide spectrum of winter conditions. They do shed some light on the potential for nutrient loss following manure application during winter with respect to cropping system effects on runoff, manure mulching effects, manure properties, and differences due to manure placement relative to a snow pack and timing of application. However, process-level understanding of nutrient loss following manure application during winter is still lacking, and critical variables that control hydrologic and transport processes under winter conditions are not fully identified or understood. Extensive watershed-scale observations in combination with plot and field scale experiments that focus on specific processes should yield sufficient knowledge and data to develop empirical models, a useful first step in developing more detailed understanding of nutrient losses associated with manure spreading under winter conditions.

Keywords: Frozen soil, manure, nitrogen, nutrient loss, phosphorus, snow, winter

Manure management associated with livestock operations has received much attention because land application of excess manure is viewed as a method of disposal (Shuyler and Meek, 1989). Khaleel et al. (1980) indicated that manure application rates for crop utilization are usually low compared to those for disposal purposes. Although they are essential for plant and animal production, phosphorus (P) in fresh waters and nitrogen (N) in saline coastal waters lead to eutrophication, which has become one of the most ubiquitous water quality impairments in the United States and other parts of the world. Losses of P and N from agricultural fields have been identified as a major source of these elements in water bodies. Many states have adopted nutrient management guidelines, such as the phosphorus index, that are based on the best available knowledge of soil-nutrient-hydrology interactions that affect nutrient losses in runoff to surface water bodies or movement to ground waters.

Restrictions placed on winter spreading of manure, which are common to most management guidelines developed for cold climates, potentially affect farm operations in many of the northern-tier states of the United States and almost all provinces of Canada. In the northeast and north-central United States, approximately 2.5 cm (1 in) of snow is recorded on the ground for 100 to 140 days during the winter months (USDA, 1941), and approximately 45 percent of the United States experiences freezing weather conditions during winter (Formanek et al., 1990). Restricting winter spreading is a contentious issue in these areas, because producers have strong opinions with regard to the merits of winter spreading and arguments against the alternative practice of manure storage. Restrictions on winter spreading are based more on commonly held perceptions than on research, because studies of soil and manure interactions and the hydrological processes that affect nutrient transport under winter conditions are limited and the results of observational studies are mixed. The purpose of this paper is to review the results of scientific studies relevant to the issue of winter spreading of manure, such as the effects of winter conditions on infiltration and nutrient transport via runoff and erosion.

Rationale for winter manure spreading. Despite the perceived soil and water quality concerns and unfavorable weather conditions for operating equipment and working outdoors, winter manure spreading is widely practiced. Literature indicates the following reasons for this practice (Fleming and Fraser, 2000):

1. *No need for manure storage structures:* Manure storage structures are not popular among producers despite many public cost-sharing programs. Manure storage structures need periodic maintenance. Improperly or poorly maintained manure storage structures can become point sources of pollution.
2. *More time available for manure spreading:* Fewer on-field activities occur during winter months than the growing season, allowing producers more time to apply manure. Crop production activities during the growing season may allow very little time for producers to spread both stored and fresh manures.
3. *Reduced soil compaction:* Manure application on frozen ground during winter season results in less soil compaction.

Thus, for economical and practical reasons, many producers still practice winter manure spreading. The practice can be optimized through judicious decisions about timing and rate of manure spreading, and where the application occurs on the landscape (Kongoli and Bland, 2002a; Kongoli and Bland, 2002b).

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Manure spreading can be combined with recommended best management practices (BMPs) to reduce the risk of nutrient loss. However, the remaining level of risk in comparison to winter storage and alternative spreading options is still the subject of debate. Manure stored in winter is generally applied in early spring. Bubenzer and Converse (1975) observed that the relative effect of such early spring application on soil and surface water quality compared to intermittent winter spreading is not known.

Current guidelines for winter manure management. For lack of sufficient scientific data, current winter manure spreading guidelines largely rely on the common sense of the applicator (Fleming and Fraser, 2000). Very early on, field studies recognized that nutrient exports from winter-applied manure can be a severe nonpoint source problem to water bodies (Milne, 1976). In a field study in Wisconsin, Hensler et al. (1971) observed lower crop yields when manure was applied throughout the winter than in the spring. The U.S. Department of Agriculture Natural Resources Conservation Service's Nutrient Management Standard 590 requires conservation measures when manure is applied to frozen soils with slopes greater than nine percent (Madison et al., 2003). Many states have formulated additional standards for winter manure management.

Table 1 presents the current winter manure management guidelines for many states in the United States. Whereas almost all states treat manure as a nutrient source, Maine treats manure as a nutrient source as well as a waste (refer to Table 1). It is unclear how manure management varies with this perspective; however, whether it is treated as a nutrient source or as a waste, manure spreading is restricted under winter conditions in that state. Also, many of the guidelines do not distinguish between manure form—solid or liquid. In addition to Nutrient Management Standard 590, the majority of states have drawn upon state regulations for manure management. These state regulations may be reflective of local management activities. Winter manure management guidelines listed in Table 1 can be summarized as follows:

- Avoid manure spreading on areas that have "high risk" for runoff,
- Avoid manure spreading on steep slopes, and
- Avoid manure spreading on fields adjacent to water bodies.

It is evident that the manure management guidelines listed in Table 1 are very similar to management practices recommended for non-winter periods. Implementation of these guidelines in the field largely rely on the common sense of the applicator, as there may not be tools or maps available to locate areas suitable for spreading. Thus, these guidelines are very good starting points, but additional research-based tools are needed for effective implementation.

In Canada, nutrient management guidelines advise application of manure on watershed areas that have a lower probability of generating runoff, and these areas are termed as "safe" areas (Fleming and Fraser, 2000). Another form of restriction is to prohibit manure spreading anywhere on the landscape during specific periods of winter as is practiced in some Canadian provinces. In Manitoba, large-scale (greater than 400 animal units) livestock operations cannot spread manure from November 10 to April 15 (Fleming and Fraser, 2000). There is no restriction on small-scale units. In Quebec, no manure spreading is allowed between October 1 and March 31 (Fleming and Fraser, 2000). More severe winter conditions in Canada may have dictated these time-restricted guidelines. Such time-restricted guidelines exist only in Maine and Vermont in the United States (refer to Table 1).

Hydrologic processes under winter conditions. Infiltration. Winter periods in the northern United States are characterized by alternate freezing and thawing, which are known to affect soil structure and infiltration. Freeze-thaw cycles disrupt soil aggregates (Bullock et al., 1988) and accelerate soil crusting, resulting in decreased infiltration and erosion resistance (Zuzel and Pikul, 1990). The potential for nutrient transport, either in soluble form in runoff, adsorbed to soil particles, or as a component of manure particles, will vary in accordance with these processes.

Depending on the presence of soil organic matter and soil moisture content at the time of freezing, the Yearbook of Agriculture for 1955 identifies four types of frozen soil structure: concrete, honeycomb, stalactite, and granular (Storey, 1955). Presence of even a small layer of concrete structure can drastically decrease soil infiltration rate, whereas the presence of other frozen soil structures, such as honeycomb, will have little or no effect on infiltration, even across large areas (Storey, 1955). Many factors can affect the existence and extent of formation of frozen soils. Since honeycomb and stalactite frost are most prevalent in meadows and pastures, and granular is indicative of forest soils, any alteration of cultivated soils that increases their similarity to the conditions present in either of these two types of land use would decrease the occurrence of concrete frost. This includes increased organic matter (humus), crop stubble, and manure applications (Storey, 1955).

Subsequent studies confirm this early characterization of frozen soil and the effects on infiltration. Willis et al. (1961) observed that infiltration rate of frozen soil decreases with increasing soil water content at the time of freezing. Studies by Lee and Molnau (1982) supported this observation. They concluded that there is a strong inverse relationship between the soil moisture content at the time of freezing and the final infiltration rate. Steenhuis et al. (1981) noted that not all frozen soils are impermeable, and the permeability of frozen soils varies with temperature and extent of pores blocked by ice. Zuzel and Pikul (1987) indicated that soils frozen under low moisture conditions may become granulated and provide little impediment to infiltration, whereas soils frozen under high moisture contents often freeze into massive, dense, concrete-like structures that are nearly impermeable to water.

Infiltration of snowmelt is also dependent on soil conditions at the time of melt. While frozen soil may lead to runoff of snowmelt, unfrozen soil may allow infiltration depending on soil moisture conditions. Ginting et al. (1998a) reported the existence of saturated soil conditions under thawing conditions, resulting in very little infiltration of snowmelt. Studies have shown that on recently thawed fine-textured soils, very little of the snowmelt infiltrates (e.g., Baker, 1972).

Studies have also recognized the mulching effect of manure under winter conditions and its effect on moderating soil temperatures. The timing of manure application can affect the soil freezing process itself. For instance, manure applied during the fall season and left on the plowed surface moderated the soil temperature extremes over early winter (Young and Mutchler, 1976). On fall-plowed fields, manure may work effectively as a mulch to control or reduce soil erosion and runoff from spring snowmelt, thereby contributing to the conservation of soil, enhancement of infiltration, and replenishment of soil moisture for crop use (Young and Mutchler,